Evidence for GeV emission from the Galactic Center Fountain

D. H. Hartmann*, D. D. Dixon**, E. D. Kolaczyk†, J. Samimi††

*Department of Physics and Astronomy
Clemson University, Clemson, SC 29634
**Institute of Geophysics and Planetary Physics
University of California Riverside, CA 92521
†Department of Statistics
University of Chicago, Chicago IL
††Sharif University
Tehran, Iran

Abstract. The region near the Galactic center may have experienced recurrent episodes of injection of energy in excess of $\sim 10^{55}$ ergs due to repeated starbursts involving more than $\sim 10^4$ supernovae. This hypothesis can be tested by measurements of γ-ray lines produced by the decay of radioactive isotopes and positron annihilation, or by searches for pulsars produced during starbursts. Recent OSSE observations of 511 keV emission extending above the Galactic center led to the suggestion of a starburst driven fountain from the Galactic center [1]. We present EGRET observations that might support this picture.

THE GALACTIC CENTER FOUNTAIN

The center of the Milky Way may have experienced a series of explosive events [2] [3] [4]. Large scale X-ray structures, such as the north polar spur, might be explained as propagating shocks induced by these explosions [5], although other arguments suggest the north polar spur is a rather local feature. To understand the angular distribution of the X-ray features, the shock model requires an impulsive energy release of $\sim 3 \times 10^{56}$ ergs about $\sim 1.5 \times 10^7$ yrs ago. A massive black hole at the Galactic center could have released this energy, but an alternative scenario is the energy deposition from a large number of supernovae.

A typical Type II supernova injects about 1–2 $\times 10^{51}$ ergs of kinetic energy into the ISM, and contributions from pre-supernova winds may double this amount. Thus, a total of $\sim 10^5$ supernovae is needed to attain a total energy of 3×10^{56} ergs. The duration of the starburst should be $< 10^6$ yrs in order to yield a propagating shock that matches the observed X-ray features [5]. Activities observed near the Galactic center are manifest on various spatial scales, with perhaps the most

dominant feature being the expanding molecular ring. At a Galactocentric distance of ~ 200 pc, the expanding molecular ring might contain as much as 10^{55} ergs of kinetic energy [6]. Enhanced 6.7 keV line emission was detected by the GINGA satellite at a distance compatible with being associated with the ring structure [7] [8]. If this line emission originates from a hot and tenuous plasma, then the X-ray observations suggest $\sim 10^{54}$ ergs of thermal energy were injected less than $\sim 10^6$ yrs ago [9].

On smaller scales, the Galactic superbubble G359.1–0.5 suggests that a starburst of $\sim 10^{2-3}$ supernovae may have occured within the past few million years [10]. Observations of stellar populations within ~ 1 pc of the Galactic center argue in favor of starburst models involving $\sim 4 \times 10^5$ $M_\odot$ of gas (implying $\sim 10^{2-3}$ supernovae) between $5-9$ Myr ago [11]. Emission features from He I surveys of the central region also implies that at least several tens of massive stars were born within a few parsecs of the center in the last $\sim 10^6$ yrs [12] [13].

Other arguments support more extensive or intense starburst episodes. The total mass interior to 1 pc exceeds 10^6 $M_\odot$ [14]. If a significant fraction of this total mass is due to mass segregation of compact stellar remnants initially formed within the inner 10–100 pc, then the associated number of neutron stars could exceed $\sim 10^6$, for a Salpeter IMF [6]. However, the velocity that neutron stars are apparently born with may allow most of them to escape the central region. Thus, neutron stars would not contribute significantly to the mass interior to 1 pc. If the neutron stars were not produced in steady state but in a series of starbursts, one might consider the production of $\sim 10^3$ neutron stars in bursts separated $\sim 10^7$ yrs. Such starbursts would also inject over 10^{54} ergs of kinetic energy into the ISM. As noted above, however, the expanding molecular ring imply that the last energy deposition was a factor $10-100$ larger [4]. Hydrodynamic simulations of gas–star systems near galactic centers suggest that starbursts which produce $> 10^5$ supernovae could occur quasi-periodically every $\sim 10^8$ yrs [3]. Bursts of this magnitude would be expected to severely influence the gas dynamics near the center, and (to a lesser extent) the disk and the halo through the influence of the propagating shock wave.

New evidence for a recent starburst in the inner Galaxy comes from the 511 keV mapping by OSSE [15] [16]. The global map can be decomposed into two components, a disk and a bulge. In addition, the data require a "hot spot" at $l \sim -4^o$ and $b \sim 7^o$. This positive latitude enhancement was interpreted by Dermer & Skibo [1] as the result of a recent starburst ($\sim 10^6$ yrs ago) involving $\sim 10^4$ supernovae. The resulting positrons lose energy and annihilate as they are convected upward with the gas flow. In this picture one also expects the coproduction of ^{26}Al (visible on a timescale of 10^6 yrs) and cosmic rays (CRs). Shocks would also produce a non-thermal population of electrons which might produce a radio afterglow. In fact, a 4 kpc long jet-like radio feature emanating from the Galactic center region has been detected at 408 MHz [17], and is commonly known as the Galactic Center Spur (GCS). If this ~ 200 pc wide chimney indeed convects radiactive debris and CRs into the halo, we might also expect some emission in the GeV regime due to interactions of the CRs with the gas in the chimney.

DETECTION OF GEV EMISSION

The data analyzed are coadded EGRET observations through VP 429.0, selecting only events within 30 degrees of the detector zenith. The analysis method is a 2D variant [18] of the TIPSH algorithm for denoising Poisson data. In the particularly TIPSH method employed here, we specify a null hypothesis, consisting of a predicted distribution of counts/pixel in the data set. Here, we have used a hypothesis consisting of the predicted Galactic [19] and extragalactic [20] diffuse emission. TIPSH works by comparing the Haar wavelet coefficients of the data with the distribution of coefficients implied by a Poisson distribution whose pixel means (and variances) are described by the null hypothesis. Those coefficents which fall below some user prescribed significance cutoff are considered statistically consistent with the null hypothesis, and discarded. At the end, the non-zero wavelet coefficients describe the portion of the data which is "different" than the null hypothesis, within the statistics of the observations, along with some (preferably small) number of false detections (non-zero coefficients due solely to noise). For the analysis described here, we selected our significance threshhold such that the error rate was about 2%.

For the region under discussion, the denoised residual (significant differences w.r.t. null hypothesis) for the 4-10 GeV band is shown in Figure 1, overplotted on filled contours showing the 511 keV model [16]. The Galactic plane flux has been truncated to show the feature of interest, which is an apparent northward extension of the Galactic emission, at $1^\circ - 2^\circ$ longitude, extending up to about 15° latitude as seen in this plot. Though we have not yet derived a spectrum for this feature, similar analysis in the 1-2 GeV band shows no evidence for a similar feature. In the 2-4 GeV band, there does appear to be enhanced emission in this region. However, it is confused with other nearby emission, and is not nearly so distinct. A reasonable conclusion is that the spectrum of this feature is fairly hard, and distinctly different than that of Galactic cosmic-ray induced emission. Further model fitting is required to verify this. Note that this feature coincides with the "jet" seen in the radio band. Also in Figure 1 are filled contours showing the most recent OSSE 511 keV model fit [16]. Though there is an apparent latitude offset in the positive latitude feature, it can be shown that due to a strong exposure-related systematic in the OSSE observations [21], a 511 keV feature corresponding to the EGRET/408MHz "jet" would be consistent with the observed 511 keV maps.

A key question is the reality of the observed features, since when using a non-parametric estimation scheme such as TIPSH, one is always concerned with artifacts. Unfortunately, it is usually difficult (if not impossible) to assign a quantitative "significance" to a feature in a non-parametric estimate. At the time of this writing, we have not yet devised a method to accomplish this. An alternative approach would be to perform some sort of model fitting, but this has its own set of pitfalls, and must be accomplished with care. Future analyses will attempt to address this, hopefully using physically motivated models.

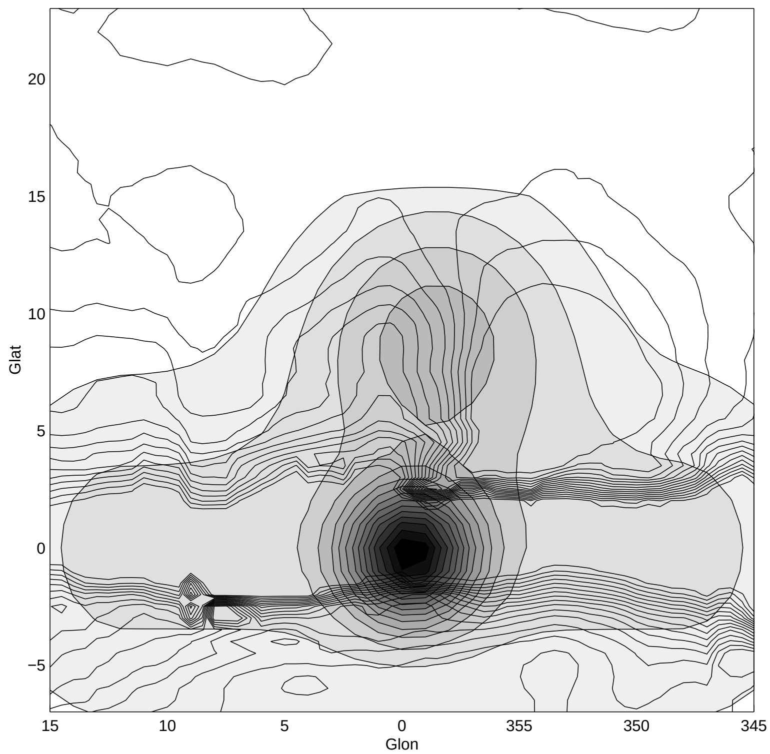

FIGURE 1. Flux contours from EGRET counts in the 4-10 GeV band. The jet-like feature is reasonably well aligned with the galactic center spur seen in 408 MHz maps. The filled contours represent the 511 keV model fit described in [16]. The apparent offset between the 511 keV and GeV features is potentially due to exposure systematics in the OSSE observations.

CONCLUSIONS

Whether driven by bursts of star formation or processes that occur near a massive black hole, the numerous activities going on near the Galactic center are hidden, for the most part, from optical observations. In the gamma-ray band evidence for starburst activity is harder to hide. Hartmann, Timmes, and Diehl [22] discussed the possibility that the production of ^{26}Al in supernovae may lead to a detectable afterglow at 1.809 MeV, and Hartmann [23] suggested that such starbursts might be detectable through an excess of radio pulsars. The detection of 1.8 MeV emission from a galactic center starburst might be accomplished by the INTEGRAL mission. The recent OSSE observations of 511 keV emission above the galactic center [15] [16] were interpreted as the result of a major galactic center starburst driving a positron fountain into the halo [1]. We present EGRET GeV observations that perhaps support this picture, but new gamma-ray missions such as GLAST will be required to verify these observations. The Galactic center is one of the most dynamical regions of our Galaxy, and high energy gamma rays may be the best tool for studying its starburst history.

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